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HYDROLOGY AND CLIMATOLOGY OF THE BRAZILIAN
AMAZON RIVER BASIN

BRAZIL

SEDIMENT STUDIES IN THE BRAZILIAN
AMAZON RIVER BASIN

UNITED NATIONS DEVELOPMENT PROGRAMME
WORLD METEOROLOGICAL ORGANIZATION
Geneva, 1980

SEDIMENT STUDIES IN THE BRAZILIAN AMAZON RIVER BASIN

by

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United Nations Development Program
World Meteorological Organization
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I. Introduction

1.1 Objective

During the month of August 1979 the writer was in Brazil as consultant on sediment transport under the auspices of the World Meteorological Organization (WMO). The assignment for this mission was set forth in a letter to the writer dated 21 March 1979 from Mr. D. H. Nijhoff, Acting Director of the Co-operation Department, WMO, Geneva (ref. 40934/BRA/72/010) as follows:

> Examine the available sediment data for the Brazilian Amazon River Basin;
>
> Recommend a plan of action for the sediment measurement and studies in the basin; examine the sampling methods, and make recommendations for measurements in very large and deep rivers; and address the 3rd Brazilian Symposium of Hydrology to be held at Brazilia from 19-23 August 1979.

The work was to be carried out as part of WMO's participation in the United Nations Development Project (UNDP) on Hydrology and Climatology of the Brazilian Amazon River Basin under the direction of Eduardo Basso, Project Manager. This project is carried out in cooperation with The General Directorate for Amazon Development of the Brazilian Government (SUDAM).

1.2 Need for Sediment Data

Experience has shown that data on the amount and kind of sediment transported by rivers is indispensable in the development and use of river waters. Among the many developments in which sediment causes problems are 1) multiple purpose reservoirs, 2) diversions of water for domestic and industrial uses, 3) diversions for irrigation and 4) development and maintenance of navigation channels.

The problems in reservoirs is to anticipate the rate at which sediment will accumulate in them and, hence, the rate at which storage volume will be lost. The data on sediment accumulation, that is, the sediment yield, must be at hand at the time that a reservoir is planned so that its useful life and economic feasibility can be determined before construction is undertaken.

The amount and grain size of sediment in river water diverted for domestic and industrial use will determine how it is to be treated before it is distributed and the cost of treatment. Obviously sediment data are needed before treatment facilities can be planned and costs determined. The sediment in river water diverted for irrigation is an important factor in the design and also in the maintenance of irrigation systems.

The development and maintenance of navigation channels in rivers often involves dredging to deepen natural channels. Dredged channels usually tend to fill up to their natural state and will require intermittent dredging to maintain the desired depth. The frequency and cost of this maintenance dredging will depend to a large extent on the amount and grain size of the sediment carried by the river.

All of the problems outlined above must be considered at the time that projects are in the planning stage. To adequately plan such projects, information is needed not only on the average amount and size composition of the sediment in a river, but also on extreme values. Such information can only be obtained by observations over substantial periods of time.

II. Sediment Measurements by Brazilian Government

2.1 Stations Listed in National Inventory

An inventory of all stream gaging stations in Brazil was published in 1979 (DNAEE 1979) by the Departmento Nacional de Aguas e Energia Eletrica (DNAEE). Those stations in the Amazon Basin and in two adjacent basins at which the inventory indicates that sediment data are collected are listed in Table 1. The two basins in addition to the Amazon Basin are those of the Rio Tocantins and of the Rio Araguari and Rio Capim near the Atlantic Coast. Although the latter three basins are not in the Amazon Basin they are of interest to the WMO Project and will be so considered. The last column of Table 1 indicates the date that the stations were established. This is interpreted to mean the date on which stream flow observations were started and not when sediment measurements were first made.

As Table 1 indicates, sediment measurements are made at 13 stations in the Amazon Basin, 10 stations in the Tocantins Basin and 4 stations in the Araguari and Capim River Basins. The watershed area of all of these basins is in excess of 7 million square kilometers. The 27 stations in this vast area cannot produce adequate sediment data for planning developments.

2.2 Stations to be Established in 1980

Table 2 lists 6 sediment stations which according to information available in the project office will be established in 1980. The first two stations in Table 2 are on the Rio Cueiras which is tributary to the Rio Negro. The station at Ponte e Lacerda is on a tributary to the Rio Guapore which flows into the Rio Madeira, a major tributary to the Amazon River. The first three stations listed in Table 2 are not listed in the inventory of stations (DNAEE, 1979) and therefore stream gaging facilities will have to be installed at these stations. Table 2 indicates that a sediment station is to be established at Obidos on the Amazon River. The inventory of stations (DNAEE, 1979) indicates that sediment measurements have been made at Obidos. It is understood that these measurements involved only taking of surface samples. Presumably the plans are to upgrade this station to include taking of suspended sediment and bed sediment samples.

The last station listed in Table 2 is in a small basin about 60 km from Manaus. Since this is in an undisturbed area the data gathered will be characteristic of the natural conditions and the erosion observed will be geologic erosion (ASCE, 1975, p. 2) that is erosion which occurs in areas which are undisturbed by works of man.

2.3 Sediment Data Obtained from Reports

A number of reports and sediment data tabulations were available in the project office. The data on sediment measurements presented in Table 3 were extracted from these reports. Six of the stations listed are not listed in the station inventory (DNAEE, 1979) and in Table 1. These stations are at Arquemes on Rio Jamari, Pedra do O' on Rio Iriri, two stations on Rio Xingu, Itupiranga on Rio Tocantins and Boa Esperanca on Rio Fresco. It is to be noted that the first measurements of those listed in Table 3 were made in 1968, but that most measurements were started in the middle to late 1970's.

The range of suspended sediment concentration is shown in Table 3 for some of the stations. The highest concentration recorded is 274 mg/e at

Itupiranga on the Rio Tocantins. Even this concentration is a comparatively modest one.

III. Sediment Measurement on Cruises of the Alpha Helix

3.1 General

The research vessel Alpha Helix made cruises of the Amazon River during the high-water seasons of June-July 1976 and May-June 1977. During these cruises flow velocities were measured and suspended sediment and bed sediment samples were taken in the Amazon and its major tributaries from the mouth to Iquitos, Peru. The Alpha Helix is operated by the Scripps Institution of Oceanography and funded by the National Science Foundation. The sampling and other research was carried out by scientists and engineers from the United States, Brazil and several other countries.

The standard depth-integrating suspended sediment samplers in use in the United States and elsewhere are recommended for use in streams that are no deeper than 5 m (ASCE, 1977, p. 326). Since most flows in the Amazon Basin are deeper than 5 m, special samplers were used in the sampling program of the Alpha Helix. These samplers included a special adaptation of the point-integrating sampler and the special bag sampler which collected samples as large as 6 liters and could collect depth-integrated samples in flows as deep as 100 m (Nordin *et al.*, 1977a; Meade *et al.*, 1979a; Nordin *et al.*, 1977b).

Samples of the bed sediment of the Amazon River and its major tributaries were taken with a Standard BM-54 Sampler (ASCE, 1977, p. 337) or a pipe dredge made of a 90 cm length of 30 cm diameter pipe.

3.2 Bed Sediment

Fig. 1 shows the median sizes of bed sediment collected in the 1976 cruise of the Alpha Helix. The median size of the bed sediment of the main stem of the Amazon varies from 0.21 mm at Sta. 7 to 0.45 mm at Sta. 77. This variation is no more than the variation between several samples taken at a section of the river. Based on these data, Meade *et al.* (1979c) concluded that most of the bed sediment in the mainstem was fine (0.125 - 0.25 mm) to medium (0.25 - 0.50 mm) sand. Some of the samples contained small amounts of fine gravel (2 - 8 mm).

The bed sediment samples are useful in that they indicate the coarsest sediment that is moved as bed load as well as suspended load.

Dunes were observed frequently on the bed of the mainstem. According to Meade *et al.* (1979) these mostly had lengths of 100 to 200 meters and heights of 2 to 5 m. Occasionally dunes reached heights of 6 m and rarely of 8 m.

The grain sizes of the bed sediment of the tributaries reveal important characteristics of these rivers. The Rio Negro (Sta. 34) shows a median size of only 0.002 mm which confirms the well known fact that this river carries very little sand. Similarly, the very fine bed sediment of the Rio Jutai (Sta. 65) and of the two tributaries (Stas. 56 and 58) entering from the right also indicate that these streams carry only fine sediment. The fine bed sediments of the Rio Tapajos (Sta. 6) and of the estuary of the Rio Tocantins show that these are relatively free of sand.

3.3 Suspended Sediment

The Alpha Helix team took suspended sediment samples and measured or estimated the flow rate at several stations on the mainstem and tributaries in the 1977 cruise. Some results of these measurements reported by Meade *et al.* (1979b) are given in Table 4. The suspended sediment discharge between Iquitos and Manacapuru (see Fig. 1) varies very little considering the substantial increase in flow.

This was interpreted to mean that the sediment in this part of the river is derived mainly from the Andes and that little sediment is contributed by the Brazilian jungle. The Rio Negro is seen to contribute very little sediment, although it is estimated to contribute 20 per cent of the flow of the Amazon (Meade *et al.*, 1979b). The Rio Madeira which has its headwaters in the Andes is seen to carry high concentrations of suspended sediment.

Meade *et al.* (1979b) estimate that the mean annual suspended sediment discharge of the Amazon at Obidos was 9.3×10^8 T/yr. Oltman (1968) estimated the mean discharge at Obidos to be 157,000 m^3/sec. These values of sediment discharge and flow rate give a mean concentration of suspended sediment of 188 mg/ℓ. The drainage area of the Amazon River at Obidos is 4.640 million sq km (DNAEE, 1979). Based on these data, the sediment yield at Obidos amounts to 200 T per km^2 per yr and the denudation rate is 0.13 mm per yr.

Data on concentration and size distribution of depth-integrated suspended sediment samples at selected verticles in rivers of the Amazon Basin as reported by Meade *et al.* (1979b) are given in Table 5. Although these samples may not be representative they do give a rough indication of conditions in the various streams. On the average, the sediment load is made up of from 60 to 80 per cent silt and clay (material finer than 0.063 mm) and 20 to 40 per cent sand. No sand coarser than 0.5 mm appeared in the suspended sediment samples. The Rio Madeira shows high concentrations as also shown in Table 4 and as expected because it comes from the Andes. The sediment load of the Rio Negro is very small as indicated in Table 4. Table 5 shows that some sand is carried in suspension by the Rio Negro. This is consistent with bed samples which showed that 6 per cent of the sediment was in the sand size (Nordin *et al.*, 1977a).

3.4 Distribution of Suspended Sediment in Flow

During the cruises of the Alpha Helix (Meade *et al.*, 1979a) point velocities were measured and point suspended sediment samples were taken at several verticles at a number of stations. The size distribution of each sample was also determined. Fig. 2 is a plot of suspended sediment concentration at a verticle in the Amazon River at Manacapuru. The ordinate of Fig. 2 is the ratio $(d-y)/y$ in which d = flow depth and y = distance above the bed. According to the Rouse theory (ASCE, 1975, p. 76) the distribution of concentration is given by

$$\frac{c}{c_a} = \left[\frac{d-y}{y} \quad \frac{a}{d-a}\right]^z \qquad (1)$$

in which the exponent z is proportional to the fall velocity of the sediment grains in water, c_a is a reference concentration at distance a above the bed, and c is the sediment concentration at level y.

Equation (1) will plot a straight line on logarithmic paper. The data for the various size grades of sediment are fitted well in Fig. 2 by straight lines as the Rouse theory indicates they should. The z values for the two grades of sand are not closely proportional to the fall velocity of the values of sediment discharge, friction slope, and mean bed shear stress. The sign of the change in sediment discharge depends on the roughness condition of the bed. The change in sediment discharge with increase in water temperature is positive when the bed is in the lower transition range, negative when the bed is in the upper transition range and there is no change when the bed is hydrodynamically rough. These results are summarized in Fig. 7.

Bed-Load Discharge Hypothesis - It is hypothesized that in a wide, flat-bed alluvial channel where flow is steady and uniform, neglecting the effects of surface tension, the dynamic flow conditions are uniquely specified by the following parameters: mean bed shear stress (τ_{ob}), bed slope (S_b), dynamic viscosity of the water (μ), water density (ρ), geometric mean size of the bed sediment (D_g), geometric standard deviation of bed material sizes (σ_g), and particle shape factor (S.F.), density (ρ_s), and buoyant specific weight ($\gamma_s-\gamma$) in which γ_s is the specific weight of the sediment and γ is the specific weight of the water. Then volumetric sediment discharge per unit width on and near the bed, q_{sb} (bed-load discharge) must be a function of these variables and can be written,

$$q_{sb} = \phi\ (\tau_{ob}, S_b, \mu, \rho, D_g, \sigma_g, S.F., \rho_s, \gamma_s-\gamma) \tag{2}$$

in which $\phi(\ )$ indicates a functional relation of the included variables. Bed slope affects particle transport by altering the gravitational forces which enhance and retard particle movement. In flat-bed regimes the bed slope is small and its influence on bed-load discharge may be neglected; and thus Eq. (2) is reduced to shown in Fig. 3. The difficulty in fitting a line to the data results from the large spread in sediment discharge for the high values of water discharge. The seven measurements which gave concentrations near 200 mg/ℓ were made in January and early February 1979. Such variation in sediment discharge is not uncommon in streams elsewhere. However, confidence in the data could be increased if the large variation could be explained. This variation might be due to heavy rains in highly erodible areas of the basin. If this is true one would expect the increase in concentration to be in the fine fractions of the suspended sediment.

4.2 Sediment Yield of Rio Tocantins

The line on Fig. 3 with the equation

$$G_{ss} = 640 \times 10^{-6}\ Q^{1.938} \tag{3}$$

was derived by Fortuna *et al.* (1979) in estimating the sediment yield of Rio Tocantins. Applying Equation 3 to a series of flows for the period 1949 - 1973 a net yield of 16.742 x 10^6 T/yr was obtained by Fortuna *et al.*

These authors indicated that the sill of the outlet gate of the reservoir was to be at elevation 27 m. They then determined that the volume of the reservoir below elevation 25 m, 2 m below the outlet sill, was 1427.5 x 10^6 cu m. The time to fill this volume with sediment assuming it entered the reservoir at the mean annual rate and that it compacted to 0.96 tons per cu m was calculated to be 82 years. In arriving at the net sediment yield, account was taken of the estimated amount of sediment that would pass through the reservoir. This estimate was based on the Brune (1953) curve (see also ASCE, 1975, p. 590) for trap efficiency of reservoirs.

The condition obtained when the sediment deposit reached a level 2 m below the out sill was apparently considered to be a critical one which if exceeded would interfere with power development by discharging sediment into the turbines. This can be avoided by raising the outlet. Many reservoirs accomplish this with gated intake towers which can withdraw water at any desired level. Based on the estimate of sediment yield by Fortuna *et al.* and a reservoir volume of 43 x 10^9 m^3; it is believed that the useful life of the reservoir will be several hundred years.

Assuming that the mean discharge of the Rio Tocantins to be 9208 m^3/sec the mean concentration to produce the 16.742 x 10^6 T/yr of sediment estimated by Fortuna *et al.* is 58 mg/ℓ. Based on a watershed area of 727,900 sq km (DNAEE, 1979) the net sediment yield is equivalent to only 23.0 T/km^2 which gives a very modest denudation rate of 0.014 mm per yr. Table 7 presents suspended sediment yield of several rivers. By any standard the suspended sediment yield of the Rio Tocantins is very small. Of the sediment yield of the many rivers listed by Holeman (1968) only very few had yields as small as that estimated for the Rio Tocantins.

It is clear from Fig. 3 that insufficient data have been collected to properly define the sediment transport relation. Not only are there few data but the measurements were all made in three years and chances are that extreme conditions are not represented. The substantial investment in the dam and power facilities at Tucurui justify the collection of much more data than shown in Fig. 3.

V. Field and Laboratory Procedures in Sediment Measurements

5.1 Suspended Sediment Samples

The samplers used to collect suspended sediment samples in the Amazon and nearby basins are the same as those used by Federal agencies in the United States or similar ones. The standard depth-integrating samplers cannot be used in streams deeper than 5 m. For streams deeper than 5 m which are common in the Brazilian Amazon, the point-integrating samplers must be used. With this device, an entire verticle is sampled in two or more segments. This increases the number of samples per verticle and cost of measuring sediment discharge.

A large capacity sampler developed by the U.S. Geological Survey was used successfully on the Alpha Helix expedition of 1977 (Meade *et al.*, 1969a) to obtain depth-integrated samples with one pass in flow depths as high as 68 m. Use of the sampler in deep rivers will save time in the field, laboratory and in calculating sediment discharge. It is recommended that the suitability of this sampler for use in the Amazon Basin be investigated. This investigation should include determining the accuracy with which this device samples the suspended sediment.

There are three schemes for selecting the verticles at a river cross-section where suspended sediment samples are to be taken (ASCE, 1975, pp. 335-336). The first scheme takes samples at verticles representing areas of equal water discharge. With this scheme the transit rate of the sampler must be uniform but need not be the same at all verticles. The concentration for the cross-section is the mean of the concentration at the several verticles. In the second scheme the verticles where samples are taken are uniformly spaced, the transit rate for all verticles is the same and the mean concentration is obtained from a composite of all samples at a section.

The third scheme involves measurements of velocity u and taking of suspended sediment samples and determining concentration, c, at several levels in verticles representing areas of equal water discharge. To obtain the mean concentration at a verticle, a plot is made of the product cu against y the distance above the bed at which point measurements were made. The area under the curve of uc against y divided by the mean velocity is the suspended sediment concentration at the verticle. The mean velocity, V, is determined from a plot of u against y. The mean concentration of the entire river at the section is the arithmetic mean of the concentrations at the verticles.

A cursory review of some suspended sediment data showed that the mean concentration at some stations was taken as the arithmetic mean of the concentration at verticles where suspended sediment samples were taken. As explained above, for this to be valid (scheme no. 1) the sampling verticle must represent areas of equal discharge. Review of the stream gaging data indicated that the verticles did not always represent areas of equal discharge. This will introduce errors of unknown amount in the calculations of sediment discharge. This error can be avoided by summing the product of concentration and discharge represented by the verticle and dividing the sum by the total discharge at the section. It is recommended that this latter procedure be followed when the discharge represented by the verticles are not equal.

5.2 Velocity Measurements with Sediment Sampler

Since suspended sediment samplers take in water and sediment at the ambient velocity in a flow they can be used to measure the mean velocity at verticles. The velocity is obtained from the relation $Vol = Va_s t$ in which Vol = volume of sample, V = mean velocity of verticle, a_s = area of sampler intake and t = the time that the sampler admits water and sediment.

This method is used in some instances in the sediment measurement in the Amazon and Tocantins Basins. The measurement of flow rate in which the velocity was measured with the sampler differed appreciably at times from the flow rate given by the stage-discharge relation. Obviously, such discrepancies introduce errors in sediment discharge measurements. It is recommended that velocities be measured with a current meter if at all possible. If in the interest of economy it is necessary to measure velocity with a sampler the sampler should be calibrated. This was done for the bag sampler used on the Alpha Helix expedition (Meade *et al.*, 1949a).

5.3 Bed Sediment Samples

Bed sediment samples were taken at several points in cross-sections with samplers developed by the Federal Agencies of the United States (ASCE, 1975, p. 337) or similar ones. The samples were sieved to determine their size distribution. In some cases, bed samples were taken every time and at every verticle where suspended sediment samples were taken. This gives more bed samples than needed for most purposes. The frequency of bed sampling can be reduced after a few sets of samples are taken to show the trend in sediment size with season and position in the cross-section. Ultimately bed samples should be needed only before the seasonal flood and after it.

5.4 Size Distribution of Suspended Sediment

In some cases a complete size distribution of each suspended sediment sample was determined. This involved analyzing the silt and clay with the bottom withdrawal tube (ASCE, 1975, pp. 420-424) and plotting the Oden curve to finally determine the size distribution. A complete size distribution of each sample is unnecessary. For most purposes the samples need be separated only into sand, silt and clay. Furthermore, for purposes of size distribution,samples can be combined thus saving much laboratory work (ASCE, 1977, p. 339). Some samples should also be collected for determining the density of the sediment (ASCE, 1977, p. 339).

VI. Estimating Unmeasured Sediment Discharge

6.1 Unmeasured Sediment Discharge for Rio Tocantins

Depth-integrating suspended sediment samplers collect samples to within a few centimeters of the bed of a river. This means that a portion of the suspended load near the bed and the bed load is not sampled. This is often called the unmeasured load. A number of ways have been developed to estimate this unmeasured load. Among these is the Modified Einstein Method (Colby and Hembree, 1955) which is used commonly by the U. S. Geological Survey.

Suspended sediment measurements collected on the Rio Tocantins were corrected for unmeasured load by the following methods or formulas: 1) Frijling-Kalinke*; Meyer-Peter (1948); Modified Einstein; and Toffaleti (1969). Of these four methods only the Modified Einstein Method makes use of the measured suspended sediment discharge to estimate the unmeasured load. The others are formulas which relate sediment discharge to hydraulic parameters such as depth slope and velocity and to the size composition of the bed sediment.

Total sediment discharge calculated by the four methods for the measurements made in 1978 and 1979 and listed in Table 8 were furnished to the writer by Hidroesb. The ranges in the ratio of estimated total sediment discharge to measured suspended sediment discharge for 22 measurements are given in Table 8. The values vary widely and it is not possible to judge which ones should be selected without further study. One possibility is to look at calculations made by others.

6.2 <u>Unmeasured Sediment Discharge by U. S. Geological Survey</u>

Jordan (1965) compared several methods of estimating unmeasured sediment discharge for the Mississippi River at St. Louis which has a sand bed. The methods compared were the formulas by Schoklitsch (Shulits, 1935), Myer-Peter and Muller (Myer-Peter, 1948), Kalinske (1947) and Bagnold (1956) and the Modified Einstein Method and the Colby Method (Colby, 1957). Jordan concluded that the most satisfactory estimates of unmeasured sediment discharge were given by the Modified Einstein Method and the Colby Method. The ratios of the total bed sediment discharge estimated by the several methods to the measured suspended bed sediment discharge are shown in graphs by Jordan. For the Modified Einstein Method the average of this ratio is 2.4 for low flows and diminishes to 1.5 for the highest flows. For the Colby Method the ratios are 3.6 and 1.3, respectively, for the low and highest flows. The measured suspended sediment discharge for the Mississippi River on the average consisted of

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*reference not available.

15 per cent sand and 85 per cent silt and clay. Based on this size distribution of the measured suspended load the total bed sediment discharge estimated by the Modified Einstein Method is from 1.08 to 1.21 times measured suspended sediment discharge. For the Colby Method this ratio varies from 1.05 to 1.39.

Referring to Table 8 it is seen that all methods except the Frijling-Kalinske Method give much larger total sediment discharge relative to measured sediment discharge. All of these high values appear unrealistically high.

The methods of Frijling-Kalinske, Meyer–Peter and Toffaleti are based on formulas which give the discharge of bed sediment based on bed sediment size, channel slope and hydraulic parameters. Such formulas are known to give widely different results. On the other hand, the Modified Einstein Method and the Colby Method make use of suspended sediment measurements and observed flow parameters. For this reason, the results obtained with these methods are expected to be more reliable than those based on formulas alone.

6.3 Recommended Methods for Estimating Unmeasured Sediment Discharge

As already indicated, the total sediment discharge obtained for Rio Tocantins by the Modified Einstein Method appears too high. The reason for obtaining such high values is not known. It may be due to an error in the computer program or in entering data into the program.

Based on experience of the U. S. Geological Survey, it is recommended that the unmeasured sediment discharge be estimated by the Modified Einstein Method. It is also recommended that calculations be made by the Colby Method and compared with those by the Modified Einstein Method. If the comparison is favorable, the Colby Method may be used exclusively. The advantage of the Colby Method is that the size distribution of the bed sediment is not needed, only the fraction of sand in the suspended load is needed and the calculation is very simple.

VII. Criteria for Selecting Sediment Stations

7.1 Classification of Sediment Stations According to Objectives

Sediment stations may be classified according to the principal purpose which they serve. For this report, stations are classified as special purpose or general purpose stations.

Special purpose stations are those which are established to obtain data needed to achieve a specific objective. A common objective may be to estimate the sediment yield of a river at a reservoir site such as on the Rio Tocantins at Tucurui. Another objective may be to measure the change in sediment yield resulting from developments in a basin. An example of such a station is the one on the Rio Jari at San Francisco near the extensive agricultural and timber producing development of Ludwig Enterprises (Time, 1979). Stations established to determine sediment yield under natural conditions in anticipation of developments in a basin are also classified as special purpose stations.

An example of a general purpose station is the one at Obidos on the main stem of the Amazon River. The principal objective here is to determine the rate at which sediment is carried past this station and how it is distributed in time. The data obtained at general purpose stations also may serve some special purposes which are subsidiary to the main purpose of the station.

7.2 Erosion Potential of Basins

In planning a network of sediment stations in an area as large as the Amazon Basin availability of manpower and funds will limit the extent of the network. Therefore, it is desirable to select each station so as to represent as much of the area as possible. This applies particularly to general purpose stations since the location of special purpose stations is usually dictated by the development which requires the data. Some economy can be effected by locating stations in watersheds with different erosion potentials and avoiding excessive duplication of measurements in basins with equal or similar erosion potentials. To do this an estimate is needed of the erosion potential of the basins in which stations appear to be needed to give the desired coverage.

Research workers of the U. S. Department of Agriculture have developed relations which estimate the erosion rate of agricultural land (Wischmeier and Smith, 1960; see also ASCE, 1975, p. 442). These relations were developed for small agricultural watersheds and do not apply directly to large basins. However, based on the factors which influence erosion in small watersheds one can develop a set of factors which influence sediment production in basins in general. The following is a set of factors which are judged to influence erosion in watersheds:

1. Rainfall, amount and distribution
2. Soil erodibility
3. Vegetative cover
4. Size and shape of basin
5. Slope of land
6. Developments such as roads, farms, etc.

Much of the information on the six factors listed above is available in maps covering approximately 60 to 70 per cent of the Amazon Basin. Sets of maps give information on each of the following subjects:

1. Geology
2. Geomorphology
3. Soils
4. Agricultural potential of soils
5. Vegetative cover
6. Potential use of land

The soil maps give soil type but do not indicate the erodibility of the soils. Table 9 ranks the soils from 0 to 6 according to increasing susceptibility to erosion. This was prepared by Benedito Nelson Rodrigues, Soil Scientist, of the Brazilian Company for Agricultural Research (EMBRAPA) and transmitted to the writer by Engineer Evaristo Terezo of SUDAM. The relative susceptibility to erosion of the soils has not been estimated. This will need to be done in order to classify basins according to erosion potential.

At the outset the classification of basins according to erosion potential will have to be based on the judgment of the hydrologists. Once the basins have been classified the classification procedure can be tested by measuring two basins which are judged to be similar to see if the sediment yields per area are, in fact, essentially the same.

The rating of the erosion potential has the best chance of success in relatively small basins in which the factors influencing sediment production do not vary widely. Therefore, the estimate of erosion potential should probably be applied to tributaries of the larger streams in the basin.

In the heavily vegetated jungle watersheds the sediment yield is known to be small. In these watersheds the important factors determining sediment yield are expected to be rainfall, slope of land and soil erodibility in that order of importance. As the density of vegetative cover diminishes its importance to erosion increases and the important factors controlling erosion might be ranked as rainfall vegetative cover, soil erodibility and slope.

VIII. New Sediment Stations Recommended

8.1 General Comments

The recommendations for expansion of the network of sediment stations which follow are made only after a limited study of the vast area involved. Most of the new stations recommended are already established as stream gaging stations where water quality is monitored. Other stations are suggested where regular flow measurements or stage observations are made. In some cases, stations are recommended where no observations have been made previously. Some of the stations recommended may be difficult to reach and, hence, expensive to operate. In such cases, the stations should be established at more convenient sites which will achieve the objective of the recommended stations. These objectives will be outlined in sections to follow.

The writer is indebted to Engineer Evaristo Terezo of SUDAM for his help in selecting new sediment stations. His intimate knowledge of the Amazon was most valuable in arriving at recommendations.

8.2 New Sediment Stations in Amazon Basin

Table 10 lists 25 new sites at which sediment measurements are recommended. Most of these sites are at established gaging stations where water quality is monitored and/or stages are observed daily. For established stations the official number and other data appearing in the inventory of fluviometric stations (DNAEE, 1979) are given in the table. The first column of Table 10 shows numbers assigned to the stations for convenience in referring to them.

The stations numbered 1-17 are those where water quality is observed and flow rate is measured. Of the stations 19-26 only no. 19 is established. The others are at new sites where no observations of stage or flow rate have been made.

The objective in recommending new stations was to expand the existing network to achieve a minimum coverage of sediment movement in the Basin. Except for No. 18, the stations recommended are considered to be general purpose stations in the sense that their purpose is to monitor sediment movement in the basin without reference to any specific developments. Station No. 18 is intended to monitor sediment transport to the reservoir for the hydroelectric plant at Curua'Una.

As indicated by Tables 1 and 2, there are 13 functioning sediment stations in the Amazon Basin and 6 more are planned. If the 26 stations recommended are established in the Amazon Basin this will make a total of only 45 in an area of approximately 6 million sq km. This is considered a minimum number of stations and this number should be increased as resources permit. The principal area into which expansion should occur is in the tributaries of the main streams. This should be done after the watersheds of these tributaries are rated as to erosion potential. Hopefully this classification should indicate similarities in sub-basins and permit the selection of stations which are typical of several sub-basins.

The principal objective of sediment stations should be to develop relations between suspended sediment discharge and water discharge. To do this, measurements should be made over as wide a range of flows as possible, and also over a number of seasons. Also of importance is the determination of the size distribution of the suspended load. Most of the size analyses need only determine the relative amounts of sand, silt and clay. A complete size analysis need be made for only a few samples and not all samples need be analyzed. Bed samples should be taken from time to time as the size composition of river beds does not change appreciably. Data needed to estimate the unmeasured sediment discharge should be collected for a range of flows but not for all measurements.

Several stations have been recommended on the Rio Xingu which is known to carry small amounts of sediment. Although the amount of sediment carried by Rio Xingu and several other relatively clear streams may be small, it is important to determine the amount and size of the sediment loads in such streams.

Some of the clear rivers like the Tapjos and the Xingu form lakes at their confluence with the Amazon. Station 17 on the Xingu is in such a lake. The objective in recommending this station is to determine how the sediment moves from the tributary to the Amazon. The flow in the lake of the Rio Xingu is complicated by backwater from the Amazon and measurements here will pose special problems. The information gained from these measurements may be applicable at the mouths of the other relatively clear rivers.

8.3 New Stations in Rio Tocantins Basin

It is recommended that 5 new sediment stations (Table 10, Nos. 26-30) be added to the 10 existing stations listed in Table 1. One of these stations, No. 29, is at an established gaging station. The others are at sites where no stream gagings have been made. The objectives and the types of sediment measurements to be made are as outlined in paragraph 8.2.

Station 30 of Table 10 is at Belem. The objective here is to determine the movement of sediment in the bay in and near the Port of Belem and the source of the sediment. This may be of assistance in clarifying the reason for the aggradation in the navigation channel and may suggest ways to minimize the aggradation. In trying to trace the source of the sediments which deposit in the navigation channel, it would be helpful to determine the size distribution of the sediment deposited and the amount dredged.

Measurement of sediment discharge at Belem will be made difficult by the tidal fluctuations. It is suggested that sediment measurements be made at a few verticles in the navigation channel at flood tide and ebb tide for a range of river flows. These measurements are viewed as part of a special investigation which should be of limited duration.

The station at Baião on the Rio Tocantins will monitor the changes in sediment movement due to the dam being built at Tucurui. Judging from experience elsewhere, degradation of the channel should be expected downstream of the dam. It is also to be expected that the islands and bars in the river would change and grow because of the regulation of the flow by the reservoir. Monitoring of the condition of the channel is advisable especially at and near cities and other developments. This monitoring can be done by periodic pictures from the air and from ground level.

IX. Sediment Data

9.1 Sediment Data Bank

In order to make the results of sediment measurements available to potential users, a bank for sediment data should be established. These data should be stored on magnetic tape or in similar form so they are easily accessible to potential users. As data are acquired their availability should be noted in continually updated versions of the DNAEE, 1979 inventory.

The data stored in the data bank will be those of general interest to users. For example, the data for a station may include the following for each measurement:

1. Date of measurement
2. Suspended sediment discharge in tons per day
3. Mean daily flow rate in cu m per sec
4. Stream width, mean depth and area of cross-section
5. Mean velocity
6. Size distribution of suspended load and bed sediment
7. Water temperature
8. Unmeasured sediment discharge (estimated)

The data bank should contain an index showing the following information for each station:

1. Dates of sampling
2. Type of suspended sediment samples; depth-integrated, point-integrated or surface samples
3. Bed sediment samples taken
4. State if suspended sediment discharge is calculated
5. State if unmeasured sediment discharge has been estimated

This index should be kept up to date and available to users on request.

9.2 Reports of Sediment Measurements

A short report should be prepared on each station describing features which could affect the quality of the measurements. This report should describe the procedures followed in selecting the verticles where suspended sediment samples are taken and the equipment used. Also the number of bed sediment samples routinely taken and the sampler used should be indicated. This information is probably best left in report form and duplicated when users request it.

9.3 Reports of Special Investigations

Reports similar to the Water Supply Papers of the U. S. Geological

Survey should be prepared on special investigations. These should describe measurements made, analyze the results and give conclusions. An example of a special investigation could be the study of the effect of backwater from the Amazon on sediment movement in Rio Xingu. Another would be the investigation of sediment movement in the navigation channel at Belem.

X. Wind Erosion

10.1 Wind Velocities

If in the development of agriculture in the Amazon and similar basins the land is clean cultivated, wind erosion may occur. To investigate the possibility of wind erosion, wind velocities were obtained for several stations in the Amazon Basin from the WMO/UNDP through Climatologist F. D. Queroz. These velocities are listed in Table 11. The table gives maximum velocities and mean velocities recorded in periods of several years.

10.2 Velocities at Which Wind Erosion Starts

Table 12 lists velocities at which wind erosion starts in sandy soils of different grain size. These are calculated according to Chepil (1945)(see also ASCE, 1975, p. 235). The table indicates that sands as coarse as 0.35 mm will be eroded by winds with velocities of 9 m/sec. The probability of getting severe wind erosion will depend on the frequency of high winds and the probability that land will be free of vegetative cover during the windy season. If developments call for having exposed soil the frequency of wind velocities should be determined as a step in assessing the potential for wind erosion.

XI. Miscellaneous

11.1 People Interviewed

A number of people furnished information to the writer during his stay in Brazil in August of 1979. Among these were Dr. Salati, Director of (INPA) Instituto Nacional de Pesquisas Amazonia. The writer visited INPA in Manaus and discussed the work of the project. Dr. Elena Franzinella, the sedimentation specialist for the project was on vacation. While in Belem discussions were held with the following people at CPRM: Mr. S. C. daConciẽgão, Chief Hydrology Division, Mr. N. S. Rodrigues, Chief Hydrology Section, and Mr. Ruy Santos, Sedimentation Specialist.

The writer met a number of people at the Third Brazilian Hydrology Conference in Brazilia during the week of August 19th. Among these was Mr. E. Meo de Moraes of Eletronorte who is responsible for sediment data collected by his organization. Some discussions were also had with Professor K. Uehara of the University of São Paulo and Mr. J. Fortes of Hidroesb. In Rio de Janeiro the writer visited the office and laboratory of HIDROESB. Productive discussions were held at HIDROESB with Mr. D. Rondon, Executive Director and with Mr. J. Fortes on the sediment measurements on the Rio Tocantins.

Many productive interviews were held with the staffs of WMO-UNDP and SUDAM. Among those with whom discussions were held was Mr. Eduardo Basso, Director of WMO-UNDP, Mr. Evaristo Terezo, Forest Engineer, SUDAM, and Specialists A. Verweg, F. D. Queiros, C. Osorio, C. Lucessa and A. Pashke. The writer also had the pleasure of meeting:

Dr. J. Gusmão, UNDP, Brazilia
Dr. J. Nemec, WMO, Geneva
F. Sutcliffe, WMO, New York
S. Souza, Director of SUDAM, Belem

11.2 Lectures

The writer gave a lecture to the staff of the Belem office on the subject 'Some Characteristics of Rivers'. About thirty people attended the lecture. On August 22 the writer addressed the Third Brazilian Conference on Hydrology on the Effect of Dunes on Sand Bed Streams. A lecture on 'Deposition of Sediment in Reservoirs' was prepared for presentation in Rio de Janeiro on August 28. Due to circumstances beyond the control of the writer, the lecture was not given. An abstract of the lecture was left for the files of the Belem office.

XII. Acknowledgments

The writer wishes to acknowledge the friendly cooperation of the staff of the Belem office. Without this cooperation, the report would not have been possible. In particular, the help of Eduardo Basso, Director WMO-UNDP is acknowledged. Mr. E. Terezo visited the writer in Pasadena, California during preparation of the report. Because of his intimate knowledge of the Amazon, he was able to help greatly in locating sediment stations and in explaining topographic and geomorphic features of the Basin. Mr. Carlos Osorio and Mr. F. D. Queiros furnished the writer with important information on the area. The writer wishes to acknowledge the help of Iran de Mendonca Coutinho of SUDAM for his help in making contact with organizations responsible for sediment data and in assisting with office analyses and calculations. Finally, the writer wishes to acknowledge the friendly assistance of the members of the stenographic pool, engineering draftsmen and other members of the staff.

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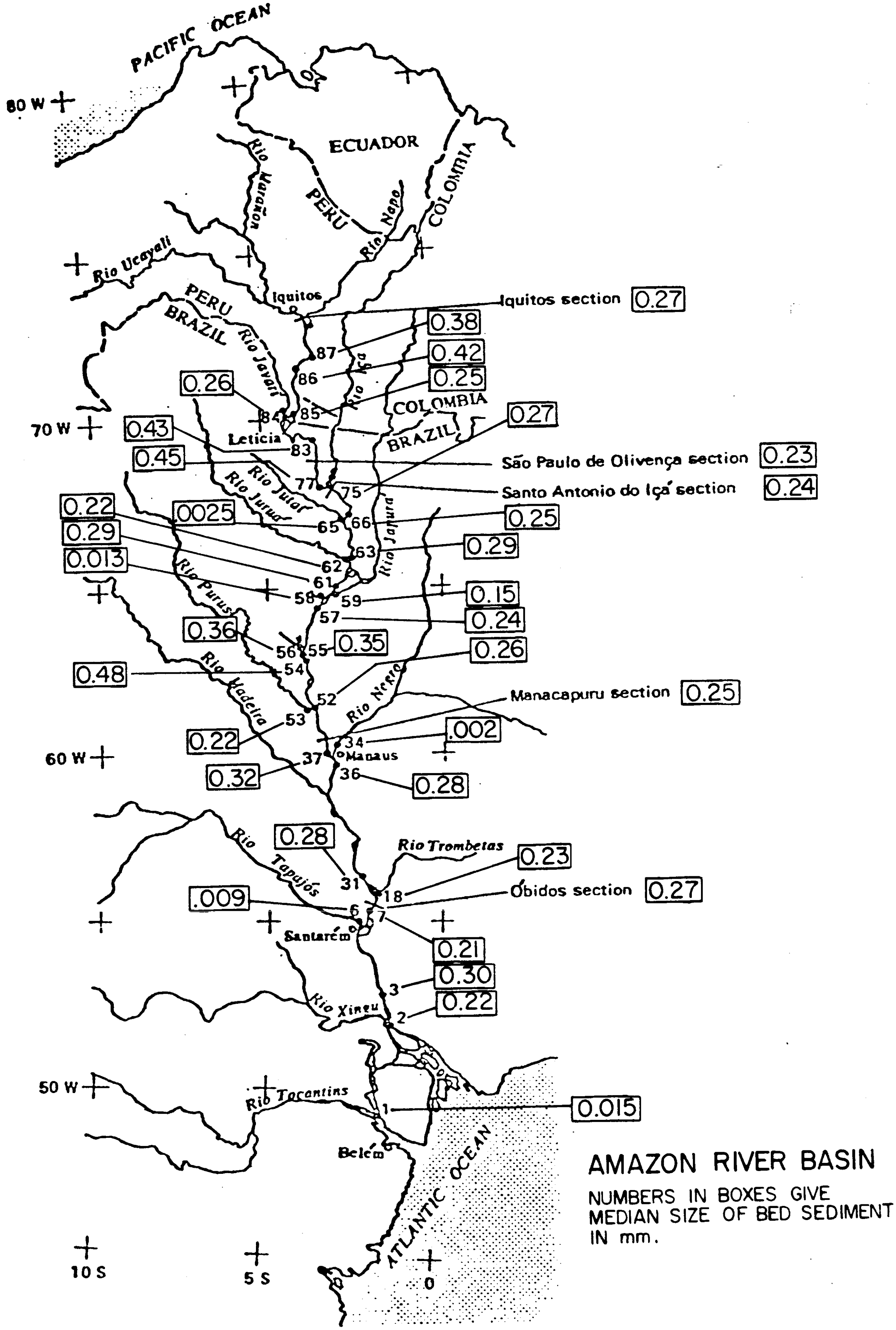

Figure 1 Median sizes of bed sediment from samples collected on cruise of the Research Vessel Alpha Helix between June 10 and July 8, 1976 (Nordin *et al.*, 1977).

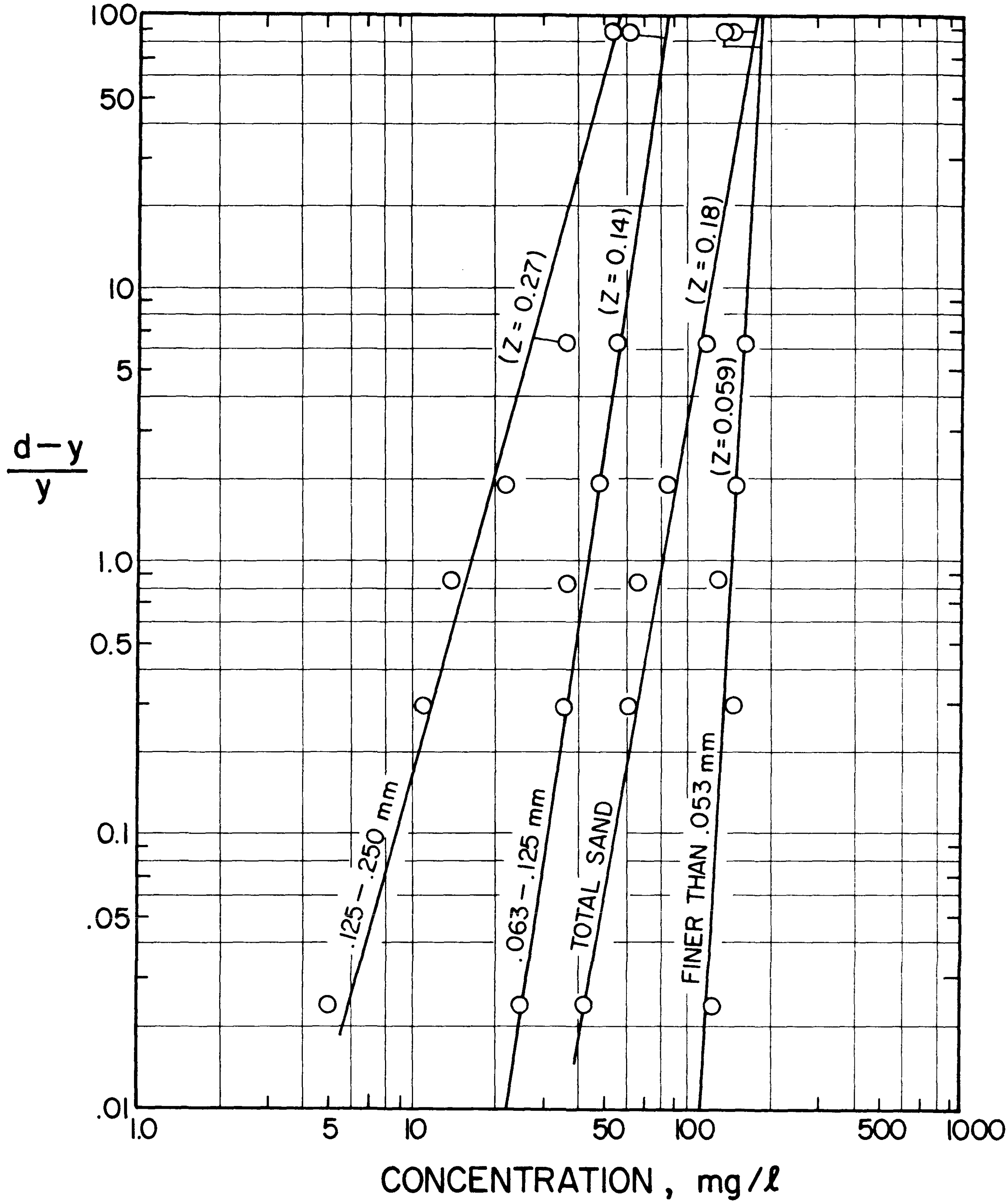

Figure 2 Distribution of suspended sediment, Amazon River at Manacapuru, cross channel station 1770 m, depth 44 m, May 27, 1977.

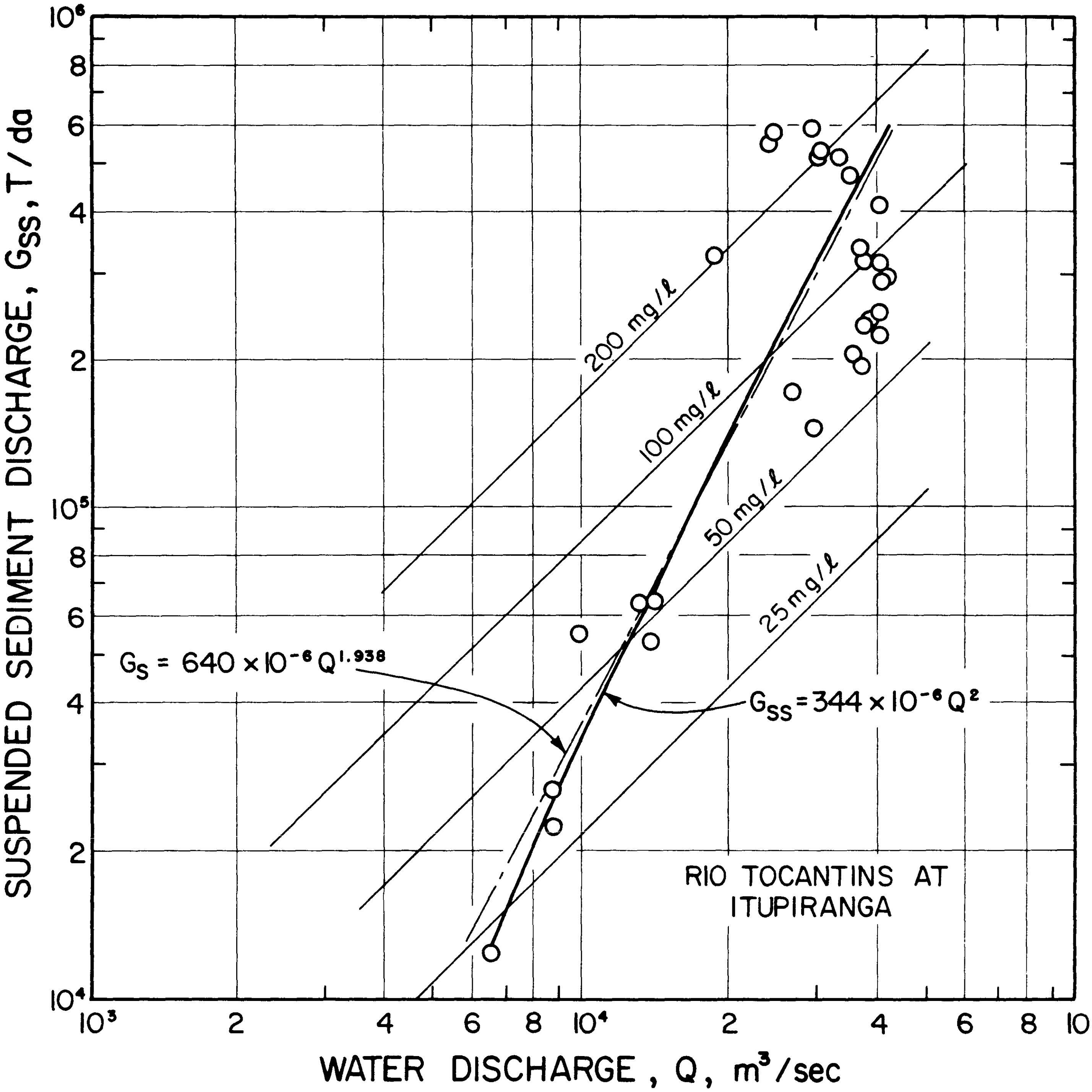

Figure 3 Sediment transport relation for Rio Tocantins at Itupiranga (see Table 6 for data).

Table 1 Sediment stations in Amazon and nearby basins listed in Brazilian national inventory of fluviometric stations.

Station No.	River	Station	Latitude*	Longitude	Area sq km	Date estab.
		1. Amazon Basin				
11200006	Solimoes	Terezina	4°-17'	69°-44'	--	12-77
11400000	Solimoes	São Paulo de Olivenca	3°-28'	68°-45'	990,253	7-73
17050001	Amazon	Obidoes	1°-54'	55°-30'	4,640,285	2-68
13600002	Acre	Rio Branco	9°-58'	67°-48'	22,363	8-67
12840000	Juruá	Gavião	4°-50'	66°-45'	189,873	6-72
14420000	Negro	Serrinha	0°-27'	64°-50'	--	8-77
15400000	Madeira	Porto Vehlo	8°-46'	63°-55'	950,582	3-72
15450000	Jamari	São Pedro	8°-59'	63°-17'	14,100	6-77
15410000	Jamari	Cachoeira Santa Cruz 2º Conjunto	10°-14'	63°-13'	4,250	6-77
15440000	Jamari	São Carlos	9°-42'	63°-08'	10,050	6-77
16080000	Uatumá	Balbina	1°-55'	59°-28'	19,260	6-77
17650000	Tapajos	Jatobá	5°-09'	56°-50'	389,331	12-72
19150000	Jari	São Francisco	0°-41'	52°-33'	48,215	7-68
		2. Rio-Tocantins Basin				
24100000	Araguaia	Cachoeira Grande	17°-09'	53°-14'	4,653	11-63
24180000	Araguaia	Baria do Peixe	16°-38'	52°-40'	14,530	9-73
27500000	Araguaia	Conceicao do Araguaia	8°-17'	49°-15'	320,290	9-69
28300000	Araguaia	Xambioa	6°-43'	48°-33'	364,496	8-69
21620000	Parana	4km Justante de Cachoeira Funil	13°-25'	47°-21'	32,142	9-73
22050001	Tocantins	Peixe	12°-01'	48°-33'	120,052	3-70
22350000	Tocantins	Porto Nacional	10°-42'	48°-26'	175,359	7-69
23600000	Tocantins	Tocantinopolis	6°-19'	47°-25'	290,570	8-69
29050000	Tocantins	Marabá	5°-21'	49°-09'	688,098	10-71
29100000	Itacaiunas	Fazenda Alegria	5°-30'	49°-14'	37,600	7-69
		3. South Atlantic Basins, North and Northeast Sections				
30300000	Araguari	Serra do Novio	0°-59'N	52°-03'	7,246	6-72
30200000	Araguari	Leonidas	0°-50'N	51°-38'	13,326	6-72
30400000	Araguari	Porto Platon	0°-44'N	51°-29'	23,590	6-52
31700000	Capim	Badajos	2°-31'	47°-49'	38,178	10-69

*all stations are south of the equator unless noted.

Table 2 Sediment stations to be installed in 1980.

Station No.	River	Station	Latitude	Longitude	Area km^2
--	Cueiras	Fl_1	5°-24'	60°-24'	--
--	Cueiras	Fl_2	5°-00'	60°-30'	--
--	Guaporé	Pontee Lacerda	15°-15'	60°-30'	--
16370000	Trombetas	Perimetral Norte	0°-31'N	56°-52'	23,171
17050000	Amazon	Obidos	1°-54'	55°-30'	4,640,285
18430000	Xingu	Passagem BR-80	10°-48'	53°-07'	139,930
--	Igarape Tarua-Acu*				23

*This is an undisturbed watershed approximately 60 km from Manaus (Hidroesb, 1979).

Table 3 Sediment measurements obtained from reports.

Station No.	River	Station	Latitude	Longitude	Area km²	Date Started	Susp. Sed. Measurements No.	Susp. Sed. Measurements Dates	References	Susp. Sed. Conc. mg/ℓ
				1. Amazon Basin						
15460000	Jamari	Cochoeira do Samuel	6°-45'	63°-28'	15,280	7-70	242	1977-1978	Sondotecnica 1977,1978	1-6
15450000	Jamari	São Pedro	8°-59'	63°-17'	14,100	6-77	6	July-Aug 1977	Sondotecnica 1977,1978	
15409000	Jamari	Santa Cruz	10°-13'	63°-13'	3,600	9-78	4	Aug-Sept 1977	Sondotecnica 1977,1978	
15440000	Jamari	São Carlos	9°-42'	63°-08'	10,050	6-77	3	July-Aug 1977	Sondotecnica 1977,1978	
15430000	Jamari	Arquemes	9°-52'	63°-05'	8,325	12-77	6	July-Sept 1977	Sondotecnica 1977,1978	
16080000	Uatuma	Cocheira do Balbina	1°-55'	59°-28'	19,260	6-77	36	Apr-Oct 1977	Hidrologia S.A. 1978	Less than 100 ppm
17650000	Tapajos	Jatoba´	5°-09'	56°-50'	389,351	12-72	5	Aug 1977-Apr 1978	CPRM*	
18700000	Iriri	Pedra do O´	4°-34'	54°-03'	119,484	9-76	3	Feb-Nov 1978	CNEC 1979	64-123
18520000	Xingu	Belo Horizonte	5°-23'	52°-53'	283,359	4-76	6	July 1978-Mar 1979	CNEC 1979	16-103
18850000	Xingu	Alta Mira	3°-12'	52°-13'	446,573	4-68	3	Aug 1978-Feb 1979	CNEC 1979	45-71
19150000	Jari	São Francisco	0°-41'	52°-33'	48,215	7-68	15	1976-1978	CPRM*	4-120
				2. Rio Tocantins Basin						
29050000	Tocantins	Maraba	5°-21'	49°-09'	688,098	10-71	3	July-Nov 1977	HIDROESB 1978-1979	14-114
29200000	Tocantins	Itupiranga	5°-08'	49°-21'	727,900	5-75	29	1975-1979	HIDROESB 1978-1979	22-274
				3. South Atlantic Basins, North and Northeast Sections						
18500000	Fresco	Boã Esperanca	6°-43'	51°-46'	43,033	11-75	5	1978-1979	CNEC 1979	48-79
31700000	Capim	Badajos	2°-31'	47°-49'	38,178	10-69	9	1977-1979	CPRM*	3-90
30300000	Araguari	Serra do Novio	0°-59'N	52°-03'	7,246	6-72	4	1977-1979	CPRM*	8-13
30200000	Araguari	Leonidas	0°-50'N	51°-38'	13,326	6-72	9	1976-1977	CPRM*	4-7
30400000	Araguari	Porto Platon	0°-44'N	51°-29'	23,590	6-52	7	1977-1978	CPRM*	5-26

*Data from tables made available by (CPRM) Companhia de Pesquisas e Recursos Minerais.

Table 4 Suspended sediment discharge and water discharge in the Amazon River Basin measured in 1977 during Alpha Helix Expedition.

Location	Date	Water Discharge m^3/sec	Suspended Sediment Concentration mg/ℓ	Suspended Sediment Discharge T/da
1. Amazon River				
Iquitos	20 May	48,000	400	1.7×10^6
São Paulo de Olivenca	22 May	70,000	275	1.7×10^6
San Antonio do Ica	23 May	80,000	245	1.7×10^6
Itapeúa (Coari)	26 May	110,000	150	1.4×10^6
Manacapuru	27 May	130,000	200	2.2×10^6
Obidos	2 June	230,000	235	4.7×10^6
2. Rio Negro	28 May	50,000	5	0.02×10^6
3. Rio Madeira	1 June	40,000	330	1.1×10^6

Table 5 Size distribution of suspended sediment at selected verticals in rivers of Amazon Basin (from Meade *et al.*, 1979b).

Station	River	No. of Verticals	Total Conc mg/ℓ	Percent Silt and Clay		Percent Sand	
				Max	Min	Max	Min
Iquitos	Amazon	4	290-435	57	86	14	43
São Paulo de Olivenca	Amazon	4	139-274	63	92	8	37
Santo Antonio do Icá	Amazon	4	89-258	59	91	8	41
Obidos	Amazon	2	118-169	77	82	18	23
Rosarinho	Madeira	2	325-350	77	78	22	23
40 km above Amazon R.	Icá	1	38	58	--	42	--
40 km above Manaus	Negro	2	3-6	67	88	20	33
50 km from Amazon R.	Madeira	3	251-399	77	78	22	23

Table 6 Flow and suspended sediment discharge data, Rio Tocantins at Itupiranga.

No.	Date	Water Discharge m^3/sec	Suspended Sediment Discharge T/da	Conc mg/ℓ
1	29-5-75	14,080	64,343	53
2	30-5-75	13,876	52,751	44
3	31-5-75	13,048	63,843	57
4	10-6-75	9,835	55,292	65
5	12-6-75	8,749	22,366	30
6	14-6-75	8,646	26,921	36
7	22-6-75	6,566	12,600	22
8	22-2-78	40,916	289,655	82
9	28-2-78	41,101	298,473	84
10	4-3-78	37,051	234,287	73
11	6-3-78	36,576	338,748	107
12	10-3-78	34,851	480,288	159
13	15-3-78	37,219	316,004	98
14	16-3-78	37,326	240,119	74
15	18-3-78	40,029	250,481	72
16	26-3-78	40,175	411,169	118
17	19-1-79	18,630	325,295	205
18	20-1-79	23,755	540,598	263
19	21-1-79	24,542	580,310	274
20	23-1-79	28,945	595,792	238
21	25-1-79	30,535	530,113	201
22	29-1-79	30,048	507,359	195
23	2-2-79	33,251	518,416	180
24	21-3-79	40,051	312,658	90
25	24-3-79	39,140	223,073	66
26	28-3-79	36,985	195,320	61
27	30-3-79	35,397	205,114	67
28	17-4-79	29,642	146,510	57
29	30-4-79	26,425	172,454	76

Table 7 Yield of suspended sediment for selected rivers.

River	Watershed Area km^2	Mean Discharge m^3/sec	Sediment Yield $T/km^2 x yr$	Denudation Rate mm/yr
Tocantins at Itupiranga	727,900	9208	23	0.014
Nile	2,979,000	2800	35	0.022
Columbia at Pasco, Wash.*	266,000	7250	35	0.022
Mississippi*	3,222,000	17,800	98	0.061
Amazon at Obidos	4,640,000	157,000	200	0.12
Ganges*	956,000	11,700	1400	0.87

*Holeman, 1968.

Table 8 Ratio of total sediment discharge estimated by several methods to the measured suspended sediment discharge for Rio Tocantins.

Method of Estimating Total Sediment Discharge	Ratio of Total to Measured Sediment Discharge		
	Mean	Maximum	Minimum
Frijling-Kalinske	1.15	1.56	1.01
Meyer-Peter	5.49	8.00	2.26
Modified Einstein	2.44	3.76	1.54
Toffaleti	5.30	9.72	1.10

Table 9 Ranking of soils according to their erodibility.*

Soil	Ranking
Hydromorphic soils (general)	0
Planosoils and hydromorphic laterite (high ground)	1
Lateritic concrecionary soils	2
Latosoils, clay texture	2
Latosoils, mean texture	3
Red-yellow podzols, clay texture	3
Red-yellow podzols, mean texture	4
Cambsoils, clay texture	4
Cambsoils, sandy texture	5
Quartz sand soils	5
Litholic soils	6
Red-yellow podzol, eutrophic, clay texture	3
Red-yellow podzol, dystrophic, mean texture	4
Hydromorphic podzol	3
Planosoil, eutrophic	1
Planosoil, dystrophic	1
Hydromorphic laterite, high ground	1
Terra Roxa, structured, dystrophic	4
Terra Roxa, structured, eutrophic	4
Yellow latosoil — dystrophic — clay texture	2
Red-yellow latosoil — or	
Dark red-yellow latosoil — eutrophic — mean texture	3
Purpose latosoil	
Hydromorphic laterite, dystrophic or eutrophic (sediment deposits)	0
Litholic soils, dystrophic or eutrophic	6
Rock outcrops	0
Alluvial soil (depressions, back sqamps)	0**
Sandy-quartz soil, dystrophic or eutrophic	5
Hydromorphic sandy-quartz soil, dystrophic	5
Alluvial sandy soil, terraces	2**
Alluvial sandy soil, valley	0**
Reddish Bruozem	4
Cambsoil, dystrophic or eutrophic, clay texture	4
Cambsoil, dystrophic or eutrophic, mean texture	5
Lateritic concretionary soil, dystrophic or eutrophic	2
Gleysoil, dystrophic or eutrophic	0
Gley hydromorphic soil, dystrophic or eutrophic	0
Solonchak (halomorphic soil)	0
Gray hydromorphic soil, dystrophic or eutrophic	0
Hydromorphic indiscriminated soil, dystrophic or eutrophic	0
Mangrove indiscriminated soil	0

*prepared by Benedito Nelson, Soil Scientist of Brazilian Company for Agricultural Research (EMBRAPA).

**the low rank in erosion potential of these soils apparently is due to their position as much as it is to their intrinsic properties.

Table 10 Recommended addition to network of sediment stations.

No.	Station No.	Station	Location Latitude	Location Longitude	Area sq km	Date Started
		I. Amazon Basin				
A. Present Water Quality Stations to be Converted						
1.	12500000	Rio Jurua at Cruzeiro	7°-37'	72°-40'	42,875	6-72
2.	12390000	Rio Eiru, Eirunepe	6°-55'	69°-56'	4,149	8-77
3.	12250000	Rio Juta at Porto Atunes	2°-55'	67°-08'	88,070	10-78
4.	12850000	Rio Japura at Acanaui	1°-48'	66°-33'	246,506	7-73
5.	13150000	Rio Solimoes at Itapeua	4°-03'	63°-01'	1,821,262	4-71
6.	13870000	Rio Purus at Labrea	7°-15'	64°-48'	228,611	3-71
7.	13962000	Rio Purus at Aruma-Jusante	4°-41'	62°-07'	48,420	11-75
8.	14540000	Rio Cotingo at Fazenda Bandeira Branca-Vietna	4°-38'	60°-29'	3,210	10-70
9.	14550000	Rio Cotinga at Maloca	3°-57'	60°-26'	6,855	9-75
10.	14710001	Rio Branco at Caracarai	1°-48'N	61°-08'	128,255	4-75
11.	15630000	Rio Madeira at Humaita	7°-30'	63°-61'	1,061,472	7-72
12.	16650000	Rio Trombetas at Cacho-eira da Porteira-Conj. 1	1°-05'	57°-02'	77,210	9-70
13.	18670000	Rio Iriri at Iriri	4°-44'	54°-34'	116,000	4-79
14.	18865000	Rio Xingu at Cana Verde	3°-16'	51°-58'	447,000	2-79
15.	18510000	Rio Xingu at Sao Felix do Xingu	6°-35'	52°-03'	256,799	6-75
16.	18530000	Rio Xingu at Sao Miguel	4°-44'	52°-44'	289,000	3-79
17.	18950003	Rio Xingu at Porto de Moz	1°-45'	52°-14'	509,530	3-79
18.	--	Rio Curuá Una upstream of Curuá Una Power Plant	--	--	--	
B. Other Stations in Amazon Basin						
19.	15850000	Rio Madeira at Novo Apriuna	5°-07'	60°-23'	1,279,500	7-72
20.	--	Rio Madeira at Nolinda de Norte	--	--	--	new
21.	--	Rio Juruema	10° approx.		--	new
22.	--	Rio Juruema	3°-30'	58° approx.	--	new
23.	--	Rio Teles Peres	10° approx.			new
24.	--	Rio Teles Peres	3°-30'	58° approx.		new
25.	--	Rio Iriri near confl. with Rio Xingu	--	--	--	new
26.	--	Rio Paru at Amazon R.	--	--	--	new
		II. Tocantins Basin				
27.	--	Rio Araguaia	14° approx.			new
28.	--	Rio Araguaia	12° approx.			new
29.	--	Rio Araguaia	10° approx.			new
30.	2980000	Rio Tocantins at Baiao	2°-41'	49°-41'	753,046	8-71
31.	--	Rio Tocantins at Belem	--	--	--	new

Table 11 Maximum and mean wind velocities in and near Amazon Basin.

Station	Period	Max Vel m/sec	Period	Mean Vel m/sec
Belem	1961-1963	4.0	1961-1974	1.2
San Gabriel da Cachoeira	1961-1963	9.0	1961-1975	0.5
Tuperinha	1961-1963	9.3	1961-1975	2.1
Porto Nacional	1961-1963	9.0	1961-1963	0.8
Manaus	1961-1963	7.0	1961-1970	1.8
Breves	1971-1975	2.6	--	--

Table 12 Velocities at which wind will start to erode sandy soils.

Grain Size mm	Velocities at which Erosion Starts m/sec
0.10	4.3
0.15	4.9
0.20	6.2
0.25	7.1
0.30	8.0
0.35	8.5
0.40	9.8